Laser scanning vibrometry measurements on a light weight building element

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Summary
The most common method to determine the sound reduction index of building partitions is to use a standardized microphone measurement method according to ISO 10140, which puts specific requirements to the acoustic properties of the transmission suit. At low frequencies, however, these requirements are difficult to be fulfilled. In an effort to solve this issue, a complementary measurement method based upon laser Doppler vibrometry is presented.

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INTRODUCTION

At present there is an increased interest in acoustics at low frequencies. This is because of the fact that, for example, modern audio equipment or (classical and modern) music instruments can produce rather high sound pressure levels at frequencies below 100 Hz, whilst the comfort requirements of modern society are increasing. Currently the frequency range for acoustic measurements is standardized from 100 Hz – 3150 Hz. However, recently building acoustic standards have been proposed to take into account frequencies down to 50 Hz.

Unlike heavy walls, lightweight walls usually have a rather low acoustic insulation performance in the lower frequency range. Thus, a change in the acoustic standards towards the lower frequency range will mainly affect the noise transmission measurement results (i.e. the single number ratings) of light-weight walls.

With the increased interest in the acoustics at low frequencies, it becomes of paramount importance that the measurement methods are sufficiently accurate. This, however, is a point of concern, as the acoustic sound fields in the sending and receiving rooms of transmission suits, for commonly encountered sending and receiving room volumes of typically 50m^3, are not diffuse at these frequencies, leading to a significant spread of measurement results between different laboratories.

In the next sections first standardized sound transmission measurement is described, as well as an alternative measurement approach, which is based on laser Doppler vibrometry.

STANDARDIZED SOUND TRANSMISSION MEASUREMENTS

Standardized measurements of the sound reduction index R_W, according to ISO 10140 [1], are based upon the measurement of the sound pressure level of a diffuse sound field in the sending room and in the receiving room, in one third octave bands. From that, a single number quantity is determined according to ISO 717-1 [2]. Such standardized measurement is typically performed in a laboratory transmission suit. The transmission facility at ATF, KU Leuven, shown in Figure 1, consists of a sending room and a receiving room, each with a volume V = 88.78 m^3 and a total surface area S = 121.15 m^2 each.

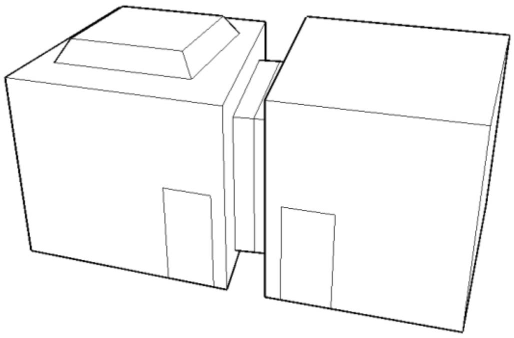

Figure 1. Sound transmission suit at ATF, KULeuven.

Basically, the ISO 10140 procedure includes the following steps. By means of a rotating boom, a microphone measurement is performed at a number (e.g. 8) of microphone positions, in both the sending and the receiving rooms (see Figure 2). The measured pressure is transformed to frequency domain, and the averaged sound pressure level L_p is determined in 1/3rd (or smaller) octave bands. An example of such a measurement is shown in Figure 3.

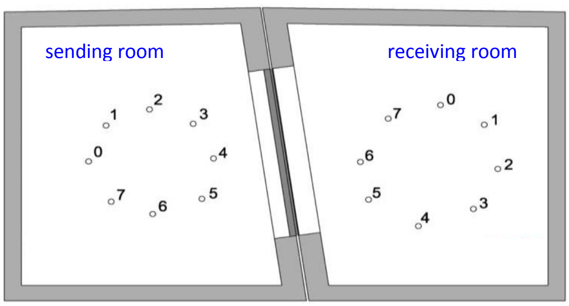

Figure 2. Example of microphone measurement positions in a transmission facility.

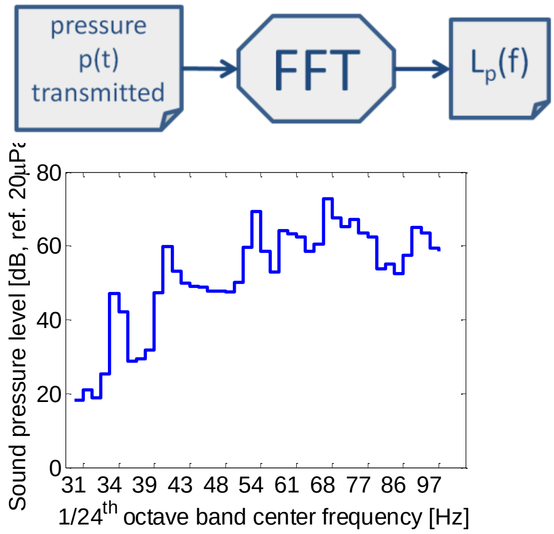

Figure 3. Averaged sound pressure level in a receiving room of a transmission facility.

In addition to the sound level measurement, the reverberation time is measured in both the sending and the receiving rooms. This is usually done by means of an MLS sequence that is sent to a loudspeaker, whilst measuring the acoustic response with a microphone, at typically the same large (e.g. 8) number of microphone positions. By analyzing the resulting impulse response, for instance by means of Dirac software (Bruel&Kjaer), the reverberation time can then be determined, typically in 1/3rd octave bands. The resulting frequency dependent reverberation time is shown in Figure 4.

Subsequently, the sound power levels L_W (dB ref 1pW) in the receiving and sending rooms are determined by the following equation

$$L_W = L_p + 10\log\left(\frac{A}{A_0}\right) + 10\log\left(1+\frac{Sc}{8Vf}\right) - 6 \text{ (dB)}$$

where L_p (dB ref 20µPa) is the spatially averaged sound pressure level, A is the acoustic absorption in the room in m^2, A_0 is the reference area of 1 m^2, S is the surface area of the room, V is the volume of the room, f is the central frequency of the measured band, and c is the speed of sound. The acoustic absorption A is related to the measured reverberation time T_{60} through Sabine's reverberation formula [3]

$$A = 24\ln(10)\frac{V}{c\,T_{60}} = 55.26\frac{V}{c\,T_{60}}$$

The resulting sound power, using the data shown in Figure 3 and Figure 4, is shown for this specific example in Figure 5.

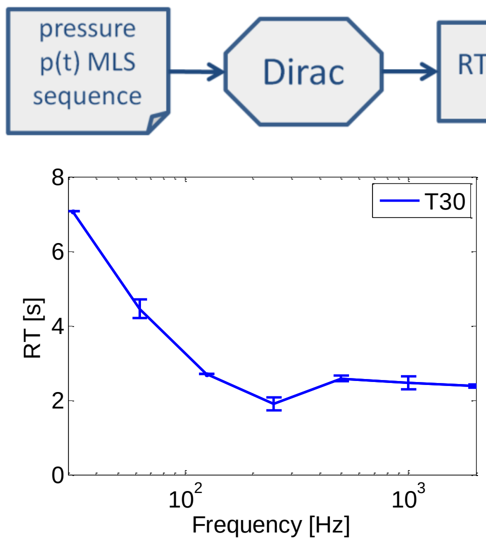

Figure 4. Averaged reverberation time in the receiving room of the transmission facility.

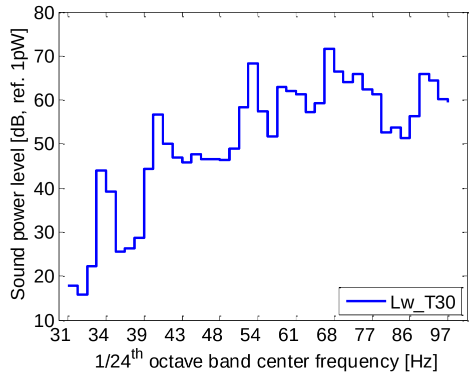

Figure 5. Averaged sound pressure level in the receiving room of the transmission facility.

A substantial problem in the lower frequency range is the low number of room modes in the lower frequency 1/3rd octave bands, causing the acoustic field to be non-diffuse. To illustrate this, the eigenfrequency repartition of the receiving room of the transmission facility of ATF, KULeuven, is shown in Figure 6. This receiving room has a net volume of 88.78 m^3. In the 100Hz 1/3rd octave band, 8 room modes exist, in the 80Hz 1/3rd octave band, 4 room modes, in the 63Hz 1/3rd octave band, 3 room modes, and in the 50Hz 1/3rd octave band, only 2 room modes. These numbers are typical numbers for transmission rooms in many acoustic laboratories.

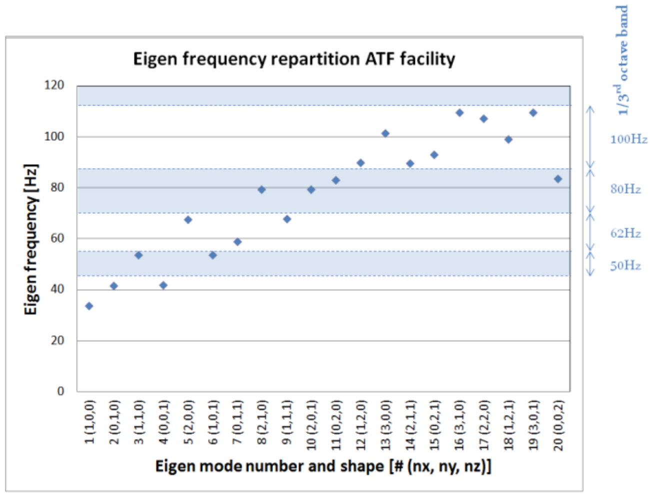

Figure 6. Eigenfrequency repartition in the receiving room of the transmission suit at ATF KU Leuven, Belgium.

It is obvious that the low number of room modes, e.g. in the 50Hz 1/3rd octave band, impede a diffuse acoustic field, making microphone measurements of the sound pressure level strongly dependent on the measurement location. Even average values obtained by scanning the microphone over different locations lead to sound reduction values that differ substantially between results obtained in different laboratories (with different shapes and dimensions).

LASER DOPPLER VIBROMETRY

Laser Doppler vibrometry is a wideband measurement method that maps the spatiotemporal dependence of the vibration pattern of the wall under test. The vibrations can either be generated mechanically, or, as in the experiment described here, by sound waves generated by a loudspeaker in the sending room .

The structural response of the wall to an acoustic sound field that is created in the sending room, was measured at a grid of measurement points (Figure 7), sequentially in time, on both sides of the walls (i.e. at the sending and at the receiving side of the panel). To retain phase information of the vibrational response on the grid of measurement points, an accelerometer at a fixed position on the wall under test was used to supply a reference signal (indicated by green lines in Figure 7).

Figure 7. Laser Doppler vibrometry measurement.

Given the vibration information, the radiated sound power was numerically calculated in to ways, i.e. with and without taking into account reflections of the transmitted sound waves by surfaces in the receiving room. In the first case, a boundary element method (BEM) was employed to model the geometry of the receiving room. An appropriate amount of damping in the model was used on the basis of measured reverberation times (see [4] and [5] for details). In the second case, the Rayleigh integral method was employed, which assumes that the wall is radiating into an infinite acoustic domain, thus leading to results that are determined by the wall insulation only, independent of the room acoustics of the receiving room.

The results are shown in Figure 8 (see also [4]). Figure 8 shows the BEM-computed sound power that is radiated by the vibrating wall.

The difference between the BEM-based estimate and the classical estimate is interesting, and the subject of further research that will be reported in [5].

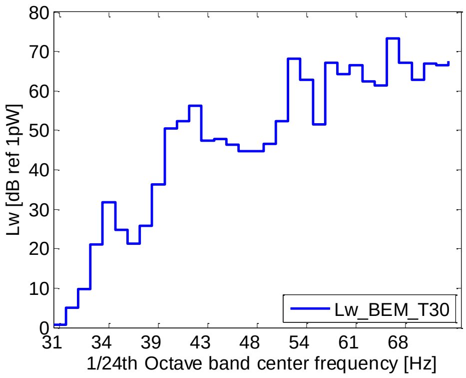

Figure 8. Laser Doppler vibrometer-BEM based acoustic power in 1/24th octave bands.

Besides the determination of the radiated sound power from the laser Doppler measurement data, a wealth of information becomes available about the effect of subtle structural details of the building element. E.g. the influence of planking fastening on the vibrational and acoustic behavior of a double wall light-weight building element was investigated in detail in reference [6], by using laser Doppler measurement data.

A laser Doppler vibrometer is preferred above the use of accelerometers, as the use of accelerometers quickly becomes impractical with the number of measurement points [7].

CONCLUSIONS

A laser Doppler vibrometry based measurement method is proposed to determine the radiated sound power of vibrating walls, which in turn can be used to determine the sound reduction index and overall sound insulation of a wall partition between a sending and receiving room. In this method, the vibration patterns of wall under test, which is excited by airborne waves in the sending room, are mapped, and numerical schemes are used to calculate the radiated sound power, both in the absence and presence of a receiving room with finite reverberation.

The laser Doppler vibrometry based measurement method is complementary to the standardized microphone based measurement method. Whilst the standardized microphone based method is easy to perform and suited to characterize walls at frequencies high enough to avoid effects of a non-diffuse sound field, the laser Doppler based method gives a possibility to get accurate sound power values, not affected by the acoustics of the room, down to very low frequencies. The LDV method is suitable for high frequency measurements as well, provided the spatial sampling step during scanning is sufficiently small with respect to the wavelength of the structure-borne waves that go along with the sound transmission.

ACKNOWLEDGEMENTS

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